SBIR Topic N99-047
Crew Centered Armament System for High Technology Cockpit

Phase I SBIR Final Report

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1 Introduction

1.1 Identification and Significance of Problem or Opportunity

The future warfighting goals of battlespace dominance, precision force and information superiority will yield in the 2025 time frame the technology for a weapons delivery capability at the disposal of a single pilot that is unmatched in history. However, the need to minimize attrition coupled with the drawdown of force levels will mean fewer pilots and aircraft will be available for missions. When these valuable assets are used, the threat of attrition will be minimal. The maximum probably of success will be needed of every sortie flown. The gating technologies for this weapons delivery capability will be:

- Battlespace Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)
- Real-time transfer of target assignment data into the cockpit
- Multi-sensor data fusion
- New high-speed avionics architectures
- High maneuverability air-to-air missiles
- GPS-guided small smart bombs.
- Advanced autonomous attack missile systems

The above technologies will be briefly discussed as follows.

<u>Battlespace Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR)</u>

The Navy's initiative for the future of C4ISR is the Copernicus concept. Copernicus is a user-centered command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) information management architecture. This design allows the decision making process to migrate from the upper echelons down to the tactical commander, or the shooter, realizing a goal of Copernicus – a true sensor to shooter environment. The Copernicus system will form an integral part of the joint C4ISR for the Warrior concept of operations in 2025. Copernicus contributes to the emerging concept of network centric warfare. Network centric warfare is enabled by C4ISR, speed of command, co-evolution of technology, organization and doctrine. Network centric warfare, diagrammed in Figure 1, consists conceptually of sensor grids and shooter grids. The sensor grids generate Battlespace awareness, synchronize Battlespace awareness with combat operations and increase the speed of information. The shooter grids exploit Battlespace awareness to generate increased combat power, to enable massing of effects versus massing of forces, and to maximize joint combat power. The payoff of the network centric warfare concept is that it changes the dynamics of competition in warfare, enables speed of command, it rapidly "locks out" an adversary's course of action and provides the competitive edge in warfare. The Copernicus architecture will bring to

the battle assured connectivity between components, services, allies and coalition partners; an infosphere conducive to true sensor-to-shooter precision engagement; reliable information that forms a common tactical picture for shooters and strategic levels alike and the ability to exploit, corrupt, deny or destroy an adversary's information through information warfare.

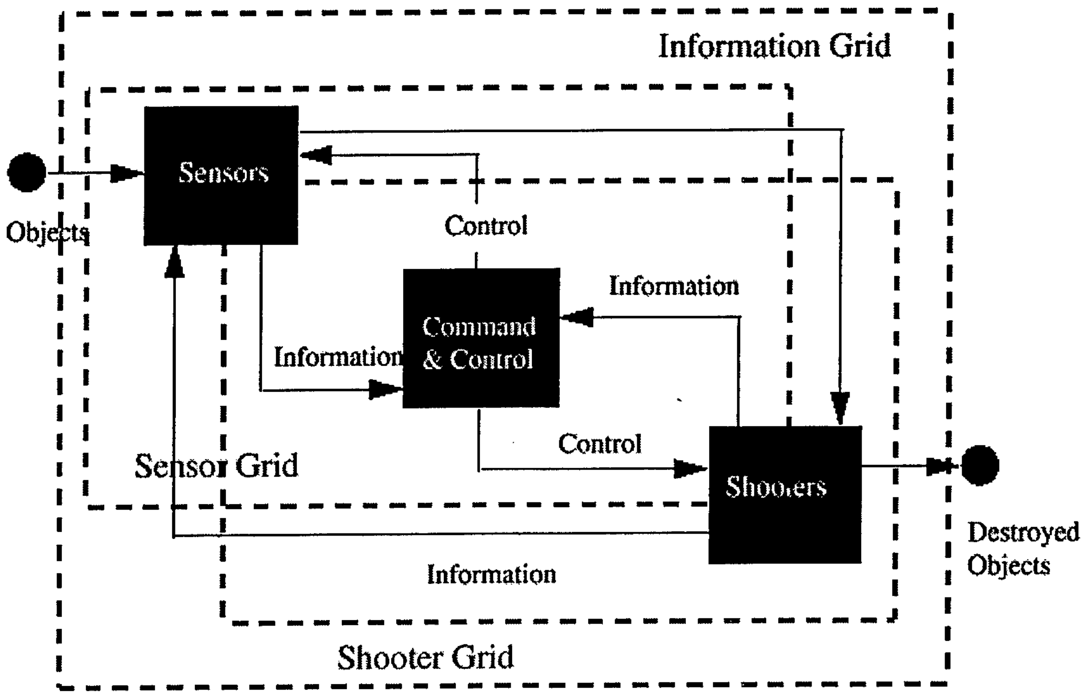

Figure 1, Network Centric Warfare Concept

Real-time transfer of target assignment data into the cockpit

The future aircraft trend is to utilize off-board information to decrease the cost and enhance performance of the next-generation aircraft. The types of off-board information anticipated to be used are the traditional existing plus potential in-theater spaceborne, airborne and surface passive assets up to in-theater active assets and the sensors/avionics within actual weapons attached to and launched by ownship or pods attached to ownship. The expected payoff for off-board data utilization is enhanced situational awareness, improved target and threat identification, information on time critical targets, performance of defensive function for ownship, support for flight mission re-planning or modification of air combat missions via updates, reduction or elimination of radiated emissions, and the capability to launch standoff air-to-surface weapons and air-to-air weapons beyond visual range. The exploitation of passive in-theater assets is referred to at real time information into the cockpit.

Multi-sensor data fusion

The fundamental description of data fusion is a process (Figure 2) that involves a hierarchical transformation between observed energy or parameters (provided by multiple

sources as input) and a decision or inference (produced by fusion estimation and/or inference processes) regarding the location, characteristics, and identity of an entity, and an interpretation of the observed entity in the context of a surrounding environment and relationships to other entities. The advantage of multi-sensor data fusion is in the statistical advantage gained in combining same-source data. In addition, the use of multiple types of sensors may increase the accuracy with which a quantity can be observed and characterized.

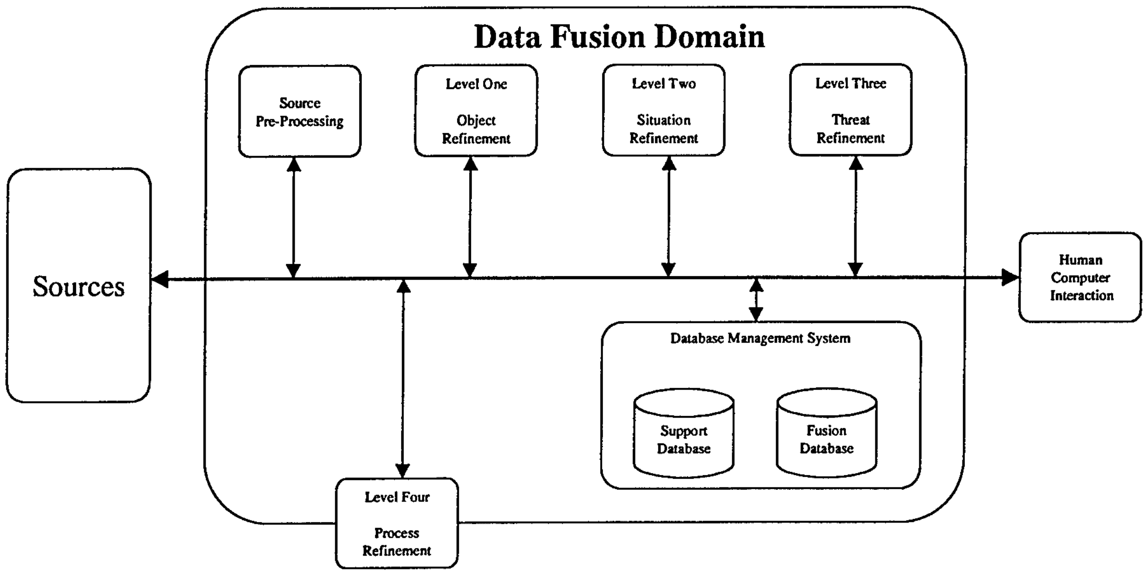

Figure 2, Data Fusion Process Hierarchy

Level One processing refines the estimates of an object's position, kinematics, attributes and identity. Level Two processing develops a description of current relationships among objects and events in the context of the environment. Level Three processing projects the current situation into the future and draws inferences about threats, vulnerability, and opportunities. Level Four processing is a meta-process that monitors data fusion processing to assess performance and refine the process to achieve goals. The Level One processing is at present the most advanced in terms of using multi-sensor data to determine the position, velocity, attributes and identity of individual objects or entities. This maturity is essential for the proposed advanced capability of the 2025 timeframe.

New high-speed avionics architectures

Future operational requirements demand a paradigm shift in the entire spectrum of core and mission avionics, as well as display technologies, man-machine interface, integration of on-board and off-board information and use of data bases. This trend is especially relevant when considering littoral warfare involving multiple forces consisting of a mix of low observable platforms, unmanned aircraft and vehicles, high density sophisticated electronic countermeasures, smart weapons, smart airframes, and information warfare. The JAST/JSF avionics architecture will be the basis for systems in the 2010 to 2040

time frame. The goals for this approach are an emphasis on affordability, open systems adaptability, scalability, incorporation of commercial technology and products, technology, independence and growth provisions, and support for high levels of reliability, maintainability, supportability and deployability. This approach takes advantage of an advanced unified digital interconnect scheme, an efficient, reliable power distribution system, proven cooling systems and extensive support for built-in test. The point of departure for the future JAST/JSF avionics architecture was the F-22. Table 1 shows the projected data rate and throughput requirements for avionics subsystems.

Table 1, JAST/JSF Data Rate and Throughput Projections

Application (Year 2010)	Data Rate Projection (per channel)	Throughput Projection (includes preprocessing)
IRST	120 - 200 Mbits/sec	4 - 10 GOPS
FLIR	120 - 160 Mbits/sec	3 - 10 GOPS
ADAS SIT Awareness Navigation Threat Warning	 150 - 700 Mbits/sec 150 - 700 Mbits/sec 150 - 700 Mbits/sec	 4 - 10 GOPS 1 - 2 GOPS 1 - 4 GOPS
RGHPRF	280 Mbits/sec	
ASLC + RGHPRF	280 Mbit/sec	2-15 GOPS
SAR	200-800 Mbits	
EW-RF (RWR/ESM)	1 -2 Gbits/sec	0.5 - 2.0 GOPS
EW-EO (Missile Warning)	SEE ADAS ABOVE	SEE ADAS ABOVE
EW-C3 (Special Receiver)	200 - 400 Mbits/sec	0.5 - 1.0 GOPS
EW-EO (Laser Warning)	50 - 100 Mbits/sec	50 - 100 MIPS
Total EO		15-25 GOPS
Total Radar		2-15 GOPS
Total EW suite		5 - 11 GOPS
Total CNI suite (WBDL+GPS+IFF)	TBD	30 - 50 GOPS*

* Normally done by specialized preprocessors

The JAST advanced avionics architecture, Figure 3, is based on the PAVE PACE program design and is a point of departure as referenced by the F-22 system. The architecture consists of an integrated core processing subsystem, and integrated RF sensing subsystem, shared RF apertures, an integrated EO sensing subsystem, a stores management system, a vehicle management system and a pilot vehicle interface as well as the interconnects among them. The unified digital avionics network provides the interconnection between the integrated core processing, the sensing functions, the vehicle management system and the pilot vehicle interface. Consideration was given to integrating the stores management system computing functions into the integrated processing unit. For systems safety reasons, the stores management systems will be isolated from the rest of the system.

High maneuverability air-to-air missiles

The Air Superiority Missile Technology Program should contribute heavily to the future of air-to-air engagements bit within visual range and beyond visual range. The Dual Range Missile incorporates the technologies of a hybrid tailfin/reaction jet flight control

system that will increase maneuverability and reduce overall missile drag; a conformal array seeker that will provide near full spherical within visual range target acquisition with virtually unlimited target track rate. When coupled with a helmet-mounted display, all aspect fire control technologies, enhanced battle situational awareness, and high off-boresight look and shoot capabilities, this missile will possess an increased no-escape zone.

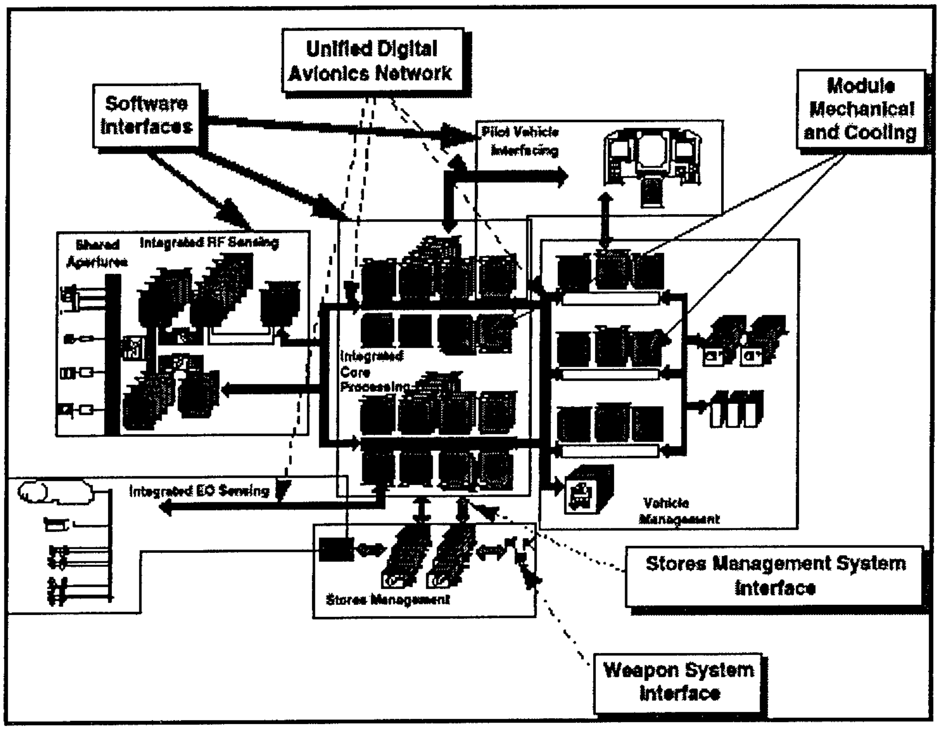

Figure 3, Proposed JAST/JSF Avionics Archetecture

GPS-Guided Small Smart Bombs.

The future trend in smart munitions is toward miniature (250 lbs.) GPS/INS guided weapons that have a kill capability comparable to 1000 lb. class weapons, but with greater accuracy and minimal collateral damage. The Miniature Munitions Capability (MMC) Program is currently undergoing Analysis of Alternatives (AoA), and is scheduled for MS I in 03. The current Miniature Munitions Technology Demonstrator (MMTD), developed by MDA (now Boeing St. Louis) for the Air Force Research Laboratory (AFRL), is 6 feet long and six inches in diameter. With the autonomous guidance of GPS and the small size, the number of kills-per-sortie for a single fighter or bomber can be tripled or even quadrupled. Current developmental carriage systems, such as the SWARMER, will be carried on the same aircraft parent rack as 1000 lb. JDAMs. These new configurations for aircraft such as JSF and F-22 will require the independent control and release of up to eight weapons from a single weapons station.

Advanced Autonomous Attack Missile Systems

The Low-Cost Autonomous Attack System (LOCAAS) employs a state-of-the-art seeker and an advanced technology warhead with three different kill modes. The capabilities of detection and ranging, seeking, increased accuracy, autonomous operation, and the ability to acquire, identify, and track targets will significantly increase sortie effectiveness. A fighter armed with 24 LOCAAS units will have the same effect as 12 fighters armed with 2 Mavericks each. The warhead is selectable between three kill modes by shaping the explosion behind a copper plate. The plate can be shaped into a long arrow-shaped rod, a slug, or a multiple fragment mode.

Human System Interface

One of the significant problems with this envisioned capability is the increase in workload for a pilot already overloaded. The increased loadout per station of small smart munitions increases the complexity of controlling and releasing these weapons. There is now not only the possibility of multiple-kills-per pass, but multiple passes-per-sortie, possibly with a mixed loadout on one station. The allocation of "smarts" between increasingly "smarter" carriage systems, the aircraft, and the munitions is clearly a system-level and aircraft-level problem that directly impacts aircraft OFP development, crew station design, and avionics architecture. Essential to this opportunity would be the reduction in pilot workload by simplifying individual tasks by the clear, uncluttered display of information, making a control easy to operate; delegating tasks to automatic or "intelligent" aiding systems; and reducing physical encumbrance from protective clothing and headgear.

1.2 The "Crew Centered" Approach to System Design.

Many efforts have claimed to use crew centered design methods to insure the usability of their design. When pushed to describe their methods few have been able to fully describe what it means to be crew-centered let alone to have a codified methodology to design from that perspective. The Navy's Advanced Technology Crew Station (ATCS) Program was the first military aircraft program to attempt to codify a process for designing with respect to the crewmember. The definition of crew-centered design from this effort was: ***Design with an emphasis on the needs of the aircrew and using a design approach focused to enhance design of the weapon system.***

Subsequent to the ATCS program was an effort put forward by NASA for the High Speed Civil Transport Aircraft to define a crew centered flight deck design philosophy. The perspective of this approach was that pilot performance is more important than performance of individual aircraft/crew station components. Aircraft and crew station system design takes place in reference to human operator limitations, and crew station and aircraft system integration issues are addressed prior to, or in parallel with, development of individual systems or components and continuous pilot-in-loop evaluations as an integral part of the design process. The basic Crew Centered Design Philosophy is as follows:

Each design decision should consider overall flight safety and efficiency. Combined flight crew/flight deck system performance is more important than local optimization of the performance of any human or automated component in that system. Overall flight crew/flight deck performance and the performance of the human and automated components are affected by qualitatively different sets of issues depending on the specific operational roles in which pilots are viewed. Flight deck design should consider these different roles. Humans and machines are not comparable; they are complementary. They possess different capabilities, limitations, strengths and weaknesses, and there is a mutual dependence required between humans and machines to successfully accomplish the mission. Safety and efficiency of flight will be maximized by focusing on ways to develop and support the complementary nature of the flight crew and the flight deck systems.

1.2.1 Pilot Roles

Inherent to their approach was the decomposition of the pilot roles in general. These roles were considered in more specificity for this program. The basic roles of the pilot were defined as team member, commander, individual operator, and occupant.

The basic design considerations for a pilot as team member are:

- The design should facilitate human operator awareness of his or her responsibilities, and the responsibilities of the other human operators and automated flight deck systems, in fulfilling the current mission objectives.
- The design should facilitate the communication of activities, task status, conceptual models, and current mission goals among the human operators and automated flight deck systems.
- The design should support the dynamic allocation of functions and tasks among multiple human operators and automated flight deck systems.
- The design should assure that team limitations are not exceeded.
- Cooperative team capabilities (e.g. use of collective resources and cooperative problem solving) should be used to advantage when necessary.
- The design should minimize interference among functions or tasks which may be performed concurrently by multiple human operators or automated flight deck systems.
- The design should facilitate the prevention, tolerance, detection, and correction of both human and system errors, using the capabilities of the human operators and the flight deck automation.

The basic design considerations for a pilot as a commander are:

- The human operator should have final authority over all critical flight functions and tasks.
- The human operator should have access to all available information concerning the status of the aircraft, its systems, and the progress of the flight.

- The human operator should have final authority over all dynamic function and task allocation.
- The human operator should have the authority to exceed known system limitations when necessary to maintain the safety of the flight.

The basic design considerations for a pilot as an individual operators are:

- The human operator should be appropriately involved in all functions and tasks which have been allocated to him or her.
- Different strategies should be supported for meeting mission objectives.
- The content and level of integration of information provided to the human operator should be appropriate for the functions and tasks being performed and the level of aiding or automation being used.
- Methods for accomplishing all flight crew functions and tasks should be consistent with mission objectives.
- Procedures and tasks with common components or goals should be performed in a consistent manner across systems and mission objectives.
- Procedures and tasks with different components or goals should be distinct across systems and mission objectives.
- The design should facilitate the development by the human operator of conceptual models of the mission objectives and system functions that are both useful and consistent with reality.
- Fundamental human limitations (e.g., memory, computation, attention, decision-making biases, task timesharing) should not be exceeded.
- Fundamental human capabilities (e.g., problem solving, inductive reasoning) should be used to advantage.
- Interference among functions or tasks which an operator may perform concurrently should be minimized.

The basic design considerations for a pilot as a flight deck occupant are:

- The needs of the flight crew as humans in a potentially hazardous work environment should be supported.
- The design should accommodate what is known about basic human physical characteristics.
- Peripheral activities which are indirectly related to the mission objectives should be supported.
- The design should account for major cultural norms.

The specific roles as related to the CCAS program are shown in Table 2. The pilot was determined to be a member of a team consisting of himself, the system automation and the network to which the aircraft was connected (for example, the shooter/engagement grid). As a commander, the pilot should have ultimate control authority over weapons release at a minimum. As an individual operator in an air-to-ground mission, the pilot acts as a pilot, shooter, sensor and processor. As an occupant, the major concern for the

pilot as far as the armament system design was concerned was the head-mounted display weight.

Table 2, Relevant Pilot Roles for CCAS.

Role	Overall Elements	CCAS
Pilot as Team Member:	▪ flight crew members ▪ flight deck automation ▪ elements of a distributed system ▪ communication, coordination, and shared functional understanding	<u>Team</u> Pilot Automation Information Network
Pilot as Commander	▪ pilot directly responsible for the success of the mission ▪ level of pilot authority over the flight deck automation ▪ ability of the pilot to delegate tasks	Ultimate control authority for weapons release.
Pilot as Individual Operator	▪ complex system of controls and displays ▪ anthropometrics, control/ display compatibility, and cognitive processing	<u>Operator</u> Pilot Shooter Sensor Processor
Pilot as Occupants	▪ living organisms within the flight deck environment ▪ accommodation ▪ protection	HMD Weight

1.3 Armament System Components

The basic components of an airborne armament system are shown in Figure 4. The stores management system interfaces to the aircraft bus. Currently the aircraft bus is the MIL-STD-1553B but will probably not be the same in the future. The stores management system interfaces with both air-to-air and air-to-surface stores via a MIL-STD-1760 interface. Various weapons are mounted via rack mounting systems but they all, except gravity dumb bombs, use the MIL-STD-1760 as the interface

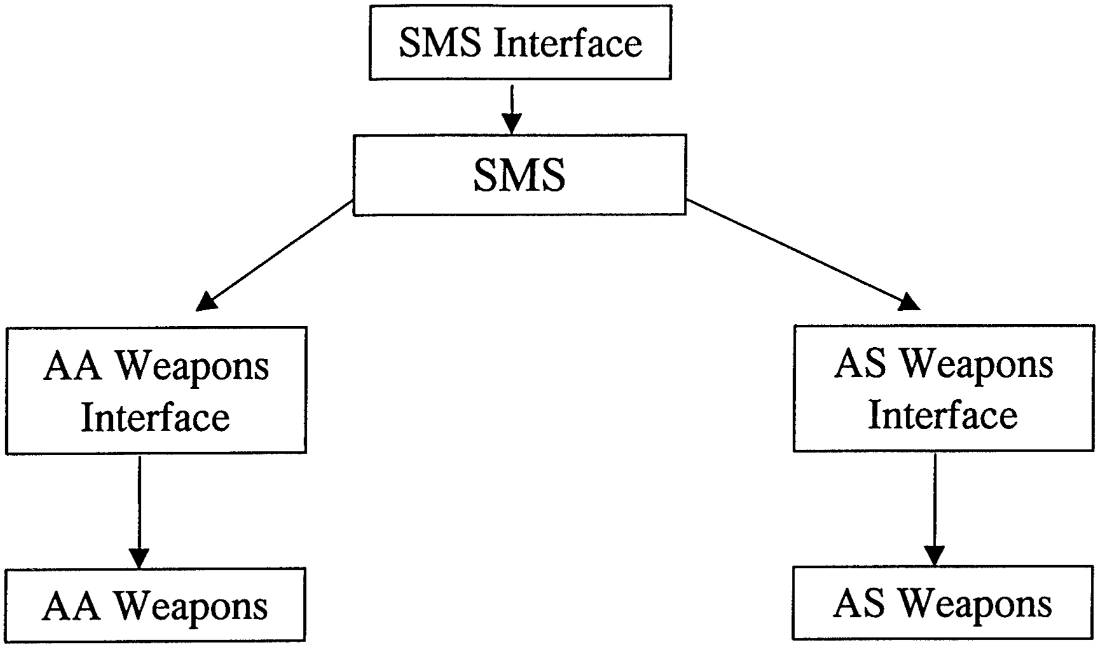

Figure 4, Armament System Components

Taking into consideration the needs of the crew member, Figure 5, a crew centered armament system actually extends from the display and control where the pilot gets information and performs the targeting and designation task through the avionics system to the stores management system and then to the individual weapon. Additional influence in pilot decision making can come from onboard and off-board data. The point of all this is to demonstrate that lags in the system through data transmission and system throughput bottlenecks as well as dependencies on the pilot to process image data, for example, lead to lags in target recognition and designation. When placed on top of this tasking the need to manage the use of a number of stores, through a display which may be cluttered with the aircraft loadout of all weapons, and perform this at low altitude and high speed, the success of the pilot is diminished.

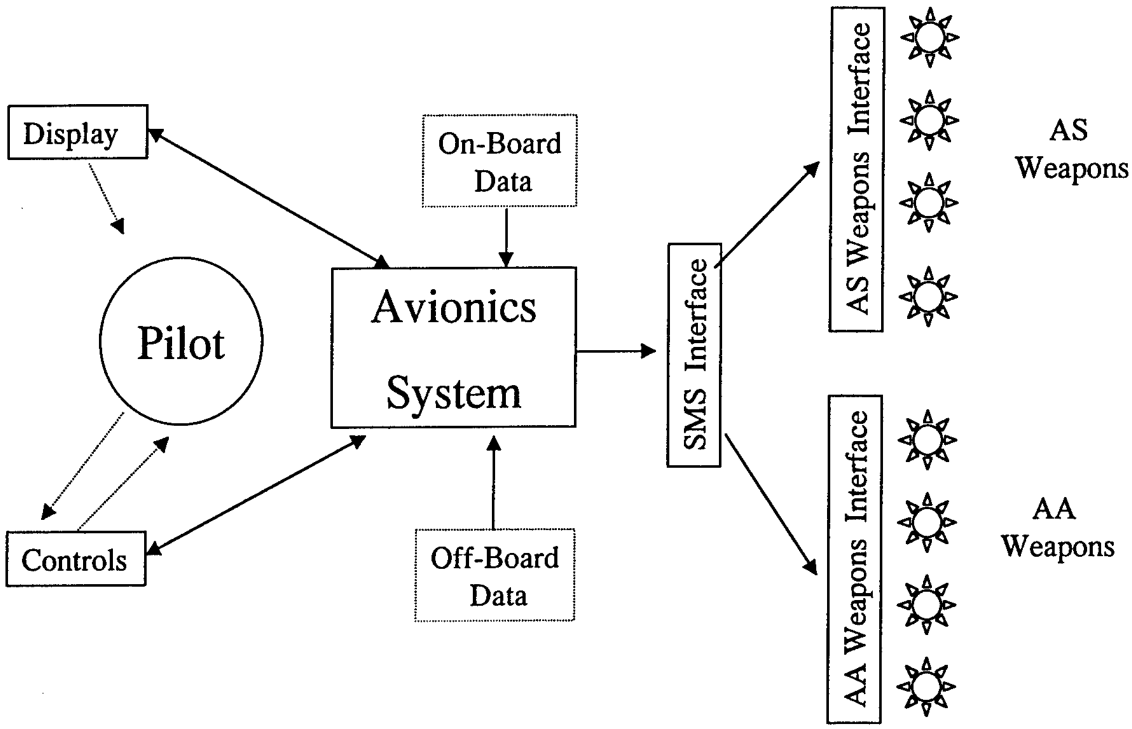

Figure 5, Additional Considerations for a Crew Centered Armament System

1.4 Phase I Technical Objectives

Objective 1: Investigate the system requirements based on the projected mission requirements and hardware in 2025.

Objective 2: For the key aircraft/armament subsystems (HMD, Controls, Avionics System and Architecture, Stores Management System, Weapon System Interface, Air-to-Air Weapon, and Air-to-Surface Weapon) investigate the technology, data and throughput requirements for mission performance and system design.

Objective 3: For the contributing aircraft subsystems (Off-Board Data System, On-Board Data System, and Data Fusion System) investigate the technology, data and throughput requirements for mission performance and system design.

Objective 4: Conceptual design of a crew-centered armament system consisting of the key armament subsystems for realization and implementation in a systems integration laboratory level demonstration in Phase 2.

2 Methods

2.1 Requirements Analysis.

The future requirements for Naval Air Warfare missions were assessed starting from the baseline (present) system and looking to the future through the present programs at the Engineering and Manufacturing Development level. The approach was taken further by looking at the Joint Warfighting and N88 Science and Technology Plans. The future aircraft complement was derived from the OPNAV *Air Warfare from the Sea* concept. These documents gave an indication of the future direction of the use of force from the sea.

2.2 Functional Analysis/Allocation.

Quality Function Deployment (QFD) is a structured method of product planning and development that translates customer wants and needs into the detailed characteristics of an end-product or service.[1] The QFD method comprises a series of matrices, each of which provides successively more detailed characteristics of the end product. The most familiar and recognizable of these matrices is the House of Quality (HOQ), the first matrix of the QFD process.

The HOQ translates the Voice of the Customer, (wants and needs stated in the terminology or jargon of the customer), into technical performance measures. Customer requirements are classified as "Whats", and are entered in the left-hand column of the HOQ. Technical performance measures are classified as "Hows" and are listed across the top row of the HOQ. The entries in the matrix can be numbers or symbols, and represent the strength of the relationships between customer requirements and the technical characteristics that are necessary to achieve the customer requirements. The exercise of developing the entries for the HOQ stimulates thought at the system level, and serves to uncover relationships and trade-offs that may not be otherwise apparent. The HOQ thus provides the initial bridge between the customer and the development team, and is often as far as a QFD process needs to be carried.

The HOQ was used for the initial framing of customer requirements for the present effort, and provided a roadmap that proved useful in defining the scope of the conceptual design effort. It was not necessary to carry the QFD process beyond the initial expository stage. The details of this effort are described in subsequent sections.

2.3 Conceptual System Design.

The conceptual system design is detailed in Section 3.3. The process is based on the functional requirements analysis and allocation, in conjunction with the assessment of

[1] "Quality Function Deployment, How to Make QFD Work for You", Cohen, L., Addison-Wesley, 1995.

future technologies and trends. The rationale and scope associated with the conceptual design process is also covered in Section 3.

3 Results

3.1 Requirements Analysis.

The activities of the Phase I effort were to investigate the future operational capability trends out to 2025, perform a functional analysis and allocation and then describe a conceptual design for a crew centered armament system. In the kick-off meeting, several simplifications were made to the overall effort. The weapons of concern were limited to Air-to-Surface weapons due to the fact that the improvements in Air-to-Air weapons were in areas that would have minimal effect on the armament system. Additionally the target aircraft to be considered was decided to be the Joint Strike Fighter (JSF) due mainly to the fact that it would be the predominant naval strike aircraft in the timeframe considered. Avionics system capability was also a consideration in selecting JSF.

3.1.1 STRIKE Air-to-Ground Mission Profile[2,3]

A representative Strike Mission Profile was prepared to provide the framework for identifying time-critical mission information requirements. The Navy Strike mission contains the following mission segments:

- Preflight
- Launch
- Climb
- Air Refueling (if necessary)
- Cruise Out
- Descent
- Ingress
- Attack
- Egress
- Climb
- Return to Force
- Descent
- Recovery
- Post Flight

The strike aircrew conducts preflight. Once preflight is complete, engine starts and taxi into position are conducted. The strike aircraft launches, climbs, and cruises out at a

[2] Advanced Technology Crew Station (ATCS) Design Methodology Program, Human Engineering System Analysis Report (HESAR), McDonnell Aircraft Company, 12 Sep 1991.
[3] Advanced Technology Crew Station, Human Engineering System Analysis Report, Volume 1, Boeing Military Airplanes, June 1991.

predetermined speed and altitude. After climb-out, rendezvous with a tanker and refueling may be required. At the planned point, a turn in-bound and descent are conducted. If escort aircraft accompany the attack aircraft, they separate from the attack aircraft and continue on their mission. Weapons and defensive systems checks are conducted and systems are confirmed operational. Preparations to enter the operational area are made. The strike aircraft ingress the operational area, navigating to the target, while flying at low altitude and avoiding terrain, enemy radar, and surface-to-air weapons. Imagery and target information is collected. The strike package crosses the Ingress Point (IP) and begins the attack phase. Navigation to the target and threat avoidance continues. Final targeting is performed along with the weapon delivery checklist prior to turning towards the target and delivering weapons. During attack, targets of opportunity may be selected and fired upon if encountered. Terrain following/terrain avoidance is continued after weapon delivery, throughout egress. During egress, there is increased attention to air-to-air threats, as well as to mobile ground threats. Once the strike aircraft egress the operational area, they climb and transit back to base. The strike aircraft descend from transit altitude, are recovered, shutdown, and postflight procedures are conducted. See Table 3 below.

Table 3, Stike Mission Phase Time History

Time	Mission Phase
-01:00 – -00:05	Preflight
-00:05 – 00:00	Launch
00:00 – 00:05	Climb
00:05 – 00:15	Air Refueling (if necessary)
00:15 – 00:45	Cruise Out
00:45 – 00:55	Descent
00:55 – 01:05	Ingress
01:05 – 01:15	Attack
01:15 – 01:25	Egress
01:25 – 01:30	Climb
01:30 – 01:40	Air Refueling (if necessary)
01:40 – 01:55	Return to Force
01:55 – 02:05	Descent
02:05 – 02:10	Recovery
02:10 – 02:30	Post Flight

3.1.2 1980s-1990s Era CVN Strike Package and Supporting Aircraft[4]

Actual strike missions are carried out by three A-6E and six F/A-18 aircraft. Along with the strike aircraft, one EA-6B, providing electronic warfare, and one single-cycle KA-6D, for aerial refueling, will comprise each strike group.

Fleet Air Defense will be carried out by four F-14A's. Sea-Control missions will be performed as follows: AEW will use one E-2C and, ASW will use two S-3Bs and one SH-3H. In addition to these aircraft, one SH-3H will always be on-station near the carrier for the SAR/PG missions.

[4] Assessment Of The Ability Of A CVN To Sustain Air Operation In A Contaminated Environment, Report # NAEC-MISC-53-010, 2 Jan 1990, NAEC Lakehurst NJ

3.1.3 Future Strike Package and Supporting Aircraft

The future strike package would more than likely consist of Joint Strike Fighter (JSF) aircraft and Unmanned Air Vehicles (UAVs) or Trans Atmospheric Vehicles (TAVs). JSF aircraft could carry a multitude of smart miniature munitions to attack ground targets. UAVs and TAVs could be outfitted with a wide variety of multi-spectral sensing equipment such as Synthetic Aperture Radar (SAR) or Light Detection And Ranging (LADAR) and act in an Early Warning capacity fulfilling the E-2C Hawkeye role. Additionally these aircraft could employ Directed Energy Weapons (DEW) such as High Power Microwave (HPM) weapons and Air Born Laser (ABL) weapons. Systems such as HPMs have the capability to destroy or damage electronic equipment, such as Surface to Air radar systems, even when the systems are turned off.[5] In this capacity they would provide electronic warfare and jamming replacing the EA-6B Prowler role. In addition to UAVs and TAVs targeting data and early warning information could be provided to the JSF aircraft from platforms such as an Joint Surveillance Target Attack Radar System (JSTARS) or Airborne Warning And Control System (AWACS) aircraft. Additionally, command and control (C^4ISR) information could be provided by these aircraft or an E-6 Mercury.

Therefore, a likely strike package could consist of five or six JSF aircraft and four UAVs. Additionally a carrier based Common Support Aircraft (CSA) or other USAF land-based tanker aircraft such as KC-135 or a KC-10 would provide air refueling capability. JSF aircraft would act in both a strike and a fighter escort role. UAVs would provide air borne reconnaissance and electronic warfare roles. Other supporting aircraft could include JSTARS, E-6 Mercury, and AWACS.

3.1.4 Miniature Munitions: The New 250 Pound Class of Small Smart Weapons

The Miniature Munitions Capability (MMC) Mission Need Statement (MNS) identified the need for a smaller, more accurate, all-weather precision guided munition for the Air Force following Operation Desert Storm (ODS). The Navy has since stated their interest in this emerging class of weapons via a memorandum of Understanding (MOU). The MMC Program is currently in Phase 0 and will pass Milestone I in 2002. The MMC Analysis of Alternatives (AoA) will select the best solution in response to the MNS.

There are currently two major concepts under consideration: Small Smart Bomb (SSB) and Anti-Materiel Munition (AMM). These concepts have been developed and tested through programs at the Air Force Research Laboratory (AFRL) at Eglin AFB. The SSB is a 250-lb. GPS-guided penetrator munition that will service fixed targets and hard targets. The AMM is a powered multi-mode shaped-charge munition that has a seeker with pattern recognition capability for servicing mobile targets. The AoA will determine which of these concepts will be carried forth to service all or part of the desired target set. Existing munitions such as the Joint Direct Attack Munition (JDAM) are also under

[5] Hit'em Where It Hurts: Strategic Attack in 2025, Lt. Col Thieret, Maj. DePalmer, Maj. Guendel, Maj. Silver, USAF, August 1996

evaluation as part of the AoA to service a portion of the desired target set. The concept(s) selected for acquisition through the MMC program could include SSB, AMM, or a combination of the two technologies. In any case, the new 250 lb. class of smart weapons will figure prominently in the mix of air-to-ground (A/G) weapons projected for the 2025 timeframe.

The SSB and the AMM are AFRL concepts that have been developed and tested through several efforts performed under contract. McDonnell Douglas (now Boeing St. Louis) conducted a flight test of a single release of the Miniature Munition Technology Demonstrator (MMTD) to demonstrate the SSB capability. Lockheed Martin Vought Systems (LMVS) developed the Low Cost Autonomous Attack Submunition (LOCAAS) to fill the AMM role.

The design characteristics of these two weapons will not be frozen until later in the acquisition process, however enough is currently known to incorporate the MMC into the CCAS system design. The SWARMER Program (Smart Weapons ARray Modular Ejector Rack) developed various carriage system loadout configuration concepts for these weapons as well as an electronics design architecture and an aircraft Interface Control Document (ICD). Four MMTD or four to eight LOCAAS could be carried on a single 1000 lb. class MIL-STD-1760 aircraft weapons station. The MMTD, as previously mentioned, is an INS/GPS-guided weapon, while the LOCAAS is a seeker-type weapon that flies a search pattern until its intended target is identified. Existing and future aircraft can adequately power both weapons in multiple carriage configurations. Independent targeting and release can be achieved as well with the appropriate aircraft software modifications. The ability to independently control and release many small smart weapons dictates the need for optimal management and allocation of these stores.

The first production multiple smart weapons carriage rack, the BRU-57 Smart Rack, provides a MIL-STD-1760 aircraft interface and a MIL-STD-1760 weapon interface. The MIL-STD-1760 interfaces include MIL-STD-1553 communications interface with aircraft and weapons. MIL-STD-1760 also defines the complete signal set for the interfaces from the aircraft through to the weapon. The '1760 signal set includes High Bandwidth, Dual Redundant Digital Data Lines, Low Bandwidth, Fiber Optic, Release Consent, Interlock, Address Lines, 28 VDC Power, 28 VDC Safety Critical Power, 270 VDC, 115 VAC, and Structure Ground in the MIL-C-38999/31 connector (25 Shell Size, Lanyard Release).

However, MIL-STD-1760 umbilical cables are relatively large and costly with regard to the requirements for 250 pound class weapons. The MIL-STD-1760 signal set exceeds the required interface for small smart weapons. The signal set, in turn, drives the number of contacts in the systems interface. The number of contacts in the systems interface drives connector/interface size and is related to separation force upon ejection for physical interface concepts (as opposed to wireless). The nominal separation force for MIL-STD-1760 connectors on a 1000 pound class weapon is 100 pounds. A 100 pound separation force is extremely significant for a 250-pound class weapon that also requires variable pitch control for safe separation. The '1760 connectors and umbilicals are also

relatively costly. For these reasons, a low cost interface is under development for small smart weapons.

The new class of small smart weapons presents a new challenge with regard to aircraft interface. The utility of these weapons is based on the ability to control and release multiple weapons from one aircraft weapons station. If these small weapons were carried as parent mission stores, there would be no force multiplication. The ability to carry four, eight, or more of these weapons on a single aircraft MIL-STD-1760 station is required to achieve the desired mission capability.

The SAE Miniature Mission Store Interface Task Group (MM/SI-TG) is currently developing a low-cost non-1760 interface standard for small smart weapons. Table 4 defines a typical miniature mission store interface signal set. This reduced signal set will allow for a significantly smaller and less expensive interface. Non-1553 communications protocols are also under consideration as part of the MMSI-TG process. To provide sufficient growth provision for future miniature mission store technologies, the MM/SI-TG has adopted an 8-bit addressing scheme. This will allow for independent communication with up to 256 miniature mission stores via a single MIL-STD-1760 ASI. The implementation of this interface, along with the aircraft logical interface defined by the SWARMER ICD, provides the foundation for maximum exploitation of the "small smart" capability for future strike missions.

Table 4, Future Miniature Munitions Signal Set.

Signal	Number of Contacts	MMSI Requirement
Main Power (28VDC)	1	Power Interface
Main Power Ret (28VDC)	1	
Main Power (270VDC)	1	
Main Power Ret (270VDC)	1	
Safety Power	1	
Safety Power Ret	1	
Safety Enable Discrete	1	Discrete Interface
Interlock	1	
Interlock Ret	1	
GPS	1	HB Interface
Tx Data (+)	1	Digital Data Interface
Tx Data (-)	1	
Rx Data (+)	1	
Rx Data (-)	1	
Shield	2	
Structure Ground	1	Ground
Addressing & Return	9	Addressing
Spares	7	Growth
TOTAL CONTACTS	33	

3.1.5 Operational Capabilities Trends from Science and Technology Plans

In the investigation of the trends in future operational capabilities out to 2025, a limitation was immediately encountered. The 1999 Joint Warfighting Science and Technology Plan (JWSTP) only goes out to 2004 – 2005, and the N88 Science and Technology Planning document target times go out to 2015 for some needs. Even with the limitations, the driving trends in naval air strike warfare that bear on armament system design were clear.

From the 1999 JWSTP the warfighting areas of Precision Force, Force Projection/Dominant Maneuver and Information Superiority are particularly important. To achieve the operational concept of precision engagement advances in these areas are essential. Precision engagement involves target acquisition, command and control to provide the ability to bring fire to bear on targets, the ability to produce the desired target effects, battle damage assessment and the ability to re-engage targets if necessary. The advances required to achieve these elements of Precision Engagement are in the areas of

mission planning, C4ISR, weapon employment and combat assessment. Critical to this project are the stated needs for communication in real time between the battlefield and fire support elements to destroy time critical targets and the ability to destroy targets at long standoff ranges with GPS-guided precision or hunter/standoff killer weapons.

The N88 Science and Technology Planning document contained specific performance objectives for capabilities that had a significant influence on the concept under development. Specifically the areas of ISR air-to-ground targeting, air-to-ground weapons, tactical situational awareness, total situational awareness and helmet systems were instrumental in guiding system performance decisions.

For ISR Air-to-ground targeting in the time period of 2010 to 2015, the stated objective was to be able to self-target in 2 seconds (sec) emitting, fixed (including hard and deeply buried), mobile, and moving targets accurately enough at soad/100 nautical miles (nmi) with a target location error (tle) of <1 meter (m), so that tle is not the determining factor in the system circular error probable (cep) of 1 m. An additional objective was to accept and autonomously insert, in real-time, (<2 sec), third party (off board) targeting data from up to a distance of 700 nmi with a tle of 1 m for all precision guided weapons against emitting, fixed, mobile, and moving targets at distances of up to 500 nmi from the strike aircraft.

For air-to-ground weapons, the objectives were to be able to hold at risk moving targets from standoff ranges of up to soad/100 nmi, hold at risk hard and deeply buried targets at ranges of up to 700 nmi, hold at risk time critical and mobile targets within 5 minutes of detection at ranges of up to 700 nmi, provide multi-mission weapons compatible with very low observable (vlo)/low observable (vo) aircraft internal and external carry options, and hold at risk SAM systems after they shutdown for 15 minutes from up to soad/100 nmi.

For tactical situational awareness, the objectives were to able to communication between all on-board and off-board sensors out to 400 nmi from individual aircraft, or radar horizon, and data fusion/decision aids systems operating in real-time, (1 sec updates) with a reliability of 100%. An additional objective was to provide situation dependent, pilot selectable display of information.

For total situational awareness in the 2010 time frame, the objectives were to provide strategic, theater, and combatant commanders complete, C4ISR information, communications and intelligent data fusion/decision aids systems to process information from all available sensors, independent of geometry, in real-time, during all weather, day and night, in any terrain, to allow geo-location and positive identification of Friend, Foe, and Neutral in the battlespace and negate the effectivity (mission impact) of jamming on GPS and communications. This information will be presented on a situation dependent, selectable display that is updated with 100% certainty of identification and location every 1 minute.

For head mounted displays the objectives were related to air-to-air weapons and engagements and not to a strike scenario.

From these science and technology objectives some relevant conclusions are derived:

- Given the desire for fast target acquisition, some level of weapon assignment automation will be required to facilitate the process.
- Real time (less than 2 sec) information into the cockpit (i.e. the SMS) will be required. This real time information will be most likely in the form of GPS target location data and not image data. The human processing of the image to recognize the target would exceed the fast target acquisition requirement. Therefore, data fusion would likely take place off-board.
- Given the long standoff ranges and desired precision of the munitions, visual acquisition of targets will not be anticipated and GPS guidance will be likely.
- Given the hold at risk requirements, the loiter, hunter/standoff killer type weapon will be also likely.

3.2 Functional Analysis/Allocation.

The Quality Function Deployment (QFD) HOQ model was used to facilitate the functional analysis and allocation of functions to aircraft subsystems. Since this is a crew-centered design, the definition of crew centered was determined and then used as the customer needs/requirements information for the QFD analysis. The pilot was viewed overall as having four roles: team member, commander, operator and an occupant. For this application, the pilot's team was considered to be him/herself, the automation and the information network. As a commander, the pilot has final control authority over weapons release. The operator roles determined were pilot, shooter, sensor and processor. The salient occupant concerns for the pilot were those for the added head weight of a head-mounted display. The initial listing of crew attributes to perform a strike mission are shown in Table 5.

Table 5, Initial List of Crew Attributes

Crew Attributes		
Primary Level	Secondary	Tertiary
Team Member	Aware of responsibilities	Pilot responsibilities
		Automation Responsibilities
		Network responsibilities
	Communicates effectively	Activities
		Task States
		Current Mission Goals
	Shares Workload (Dynamic Allocation)	Function

Crew Attributes		
Primary Level	Secondary	Tertiary
		Task
	Aware of team limits	Pilot
		Automation
		Network
Commander	Final Control Authority for	Weapons release
		All weapon stores assignment
		Dynamic allocation
	Does not exceed control authority	ROE
Operator	Pilot	
	Air-to-Surface Shooter	Possesses target information
		Manages On-board Stores
		Efficient weapon use
		Hits the target
		Hits as many targets as possible in one pass
		Shoots at a distance (long standoff range) to maximize survivability
	Sensor	"eagle eyes" – long range vision
		Uses more than one spectrum
		Effective resolution
		Uses more than one dimension
	Processor	Minimizes use of human processor limitations
		Maximizes use of human processor capabilities
Occupant	Experiences minimal neck fatigue	
	Does not get neck injury	

The "pilot" aspect of the crew attributes was not to be considered because it does not influence the development of the armament system directly. To achieve those crew attributes the following preliminary system functions were determined to be required:

System Functions

Team Member
- Task management between team members
- Function allocation between team members
- Display of team workload for pilot
- Display of function allocation for pilot
- Dynamic allocation of workload

Commander
- Weapons release discrete control
- Stores type/allocation menu control
- Weapons release advisory display
- Stores allocation/type display
- Workload allocation menu
- Workload allocation display
- RTIC to transmit command authority on ROE
- Command information display
- Command information advisory tone

Operator
- On-board targeting image data
- Off-board targeting image data
- On-board targeting GPS data
- Off-board targeting GPS data
- RTIC on target priority
- Automated tracking of stores utilization
- User control to allocate store
- Off-board target type-weapon type data
- Off-board target type- weapon type numbers data
- User controlled target type w/ automatic weapon type allocation
- User control target type w/ automatic weapon numbers allocation
- User target designation control
- User target designator display reticule
- RTIC target data
- Multiple target designation by user
- Long Rage GPS A to S
- Self-configurable GPS A to S weapons
- Many small GPS-programmable A to S weapons
- On board long range vision
- RTIC theater vision
- FLIR sensor
- I2R sensor
- RF sensor
- Radar sensor
- Microwave sensor
- RTIC battlecube (multidimensional "picture")

- A/c and theater assets handle memory tasks
- A/c and theater assets handle computational tasks
- A/c and theater assets handle attention monitoring tasks
- A/c and theater assets handle decision framework tasks
- User handles problem solving
- User handles inductive reasoning
- User handles pattern recognition

<u>Occupant</u>
- Minimize neck fatigue
- Minimize neck injury
- Minimize mental fatigue
- Minimize physical fatigue

An interesting aspect of this exercise was the requirement for a task manager as part of the aircraft system that was not previously considered. This all inclusive task manager was determined to be beyond the scope of this effort but is important to the armament system concept of this effort.

As the analysis progressed, the only higher level roles that remained were those for commander and operator as shooter and sensor. As a team member, the analysis suggested that a task manager would be appropriate but beyond the intent of this effort. A task management function was, however, relevant to the automated SMS concept and was retained as part of this effort. The operator role of pilot was inherent and did not affect the armament system design except to support the need for automation in the SMS to decrease workload. The operator role as processor was more useful as a design philosophy where the human cognitive processing strengths and weaknesses would drive the allocation of the types of operations performed by the system and the human. The occupant concerns of added head weight were not inherently a driver for armament system design especially in light of the lack of evidence for a future need to visually acquired air-to-ground targets.

The specific final control authority desired attributes were defined as control over weapons release, weapon stores assignment and weapon employment based on possible real-time changes in rules of engagement. The specific shooter desired attributes were defined as possesses target information, manages on-board stores, uses weapons efficiently, hits target, hits multiple targets in a single pass, and shoots at a distance. The specific sensor derived attributes were defined as possesses long range vision (theater assets), uses more than one spectrum, achieves effective spatial resolution and uses more than one information source. The sensor concept here is not necessarily the eyes (probably not likely to be eyes on target) but use of all network assets. The inclusion of the operator-sensor role may seem in conflict with the N88 science and technology goals indicating little need for pilot image observation for targeting. This role was retained for consideration to address the possible ROE for eyes on target in specific conditions.

The set of specific attributes was used to define the engineering response to fulfill these needs. The engineering response in general included pilot final control authority,

automation of weapon allocation, bookkeeping and accessibility in the SMS, real-time transfer of GPS target location and target type into the SMS, and off-board data fusion of image data. The QFD HOQ is located in Appendix A.

The significant result from the initial HOQ effort is that, as discussed earlier, many of the functions required to realize the system-level requirements will be allocated to higher-level avionics systems and off-board systems resident on a variety of platforms within the network. For example, while the fusion of a variety of sensor inputs is required, this will not be performed by the armament system. The entries in the HOQ matrix thus revealed that only a small subset of the conceptual design characteristics will allocate to the Stores Management System (SMS). For this reason, the QFD process, while useful for the initial synthesis of requirements, was not carried forward into the conceptual design phase. The problem was, at this stage, well bounded enough to preclude the additional expenditure of resources on the QFD process.

3.3 Conceptual System Design.

The conceptual system design phase concentrated on an automated SMS for advanced air-to-surface weapons. The decision to center on this one aspect was made for several reasons. Due to the high task loading for the assignment and release of a large number of different types of weapons, automation of that process was determined to be required. Given the future capabilities of the systems on the information network to process off-board data, the desired capability to rapidly designate targets coupled with the inherent delays in human processing, an assumption was made that no image data would be transmitted to the pilot for human pattern recognition and target designation. This assumption led to the position that all target data would be GPS coordinates for location and target type for numbers and types of stores. Given the long standoff ranges for weapons release, visual acquisition of targets seemed to be impractical, so an assumption was made that visual target acquisition was not desirable, and that therefore the head mounted display's major role was for air-to-air targeting with little role in air-to-ground. However displaying the targeting display information on the head-mounted display may reduce the incidence of spatial disorientation that occurs when pilots make the transition from out-to-in-to-outside the cockpit. The last consideration for focusing on an automated SMS was to forward a tangible product into Phase II that would be usable in military and commercial applications.

The system concept as it exists in this iteration will be able to receive GPS target location and target type data over the avionics bus, which may have to be emulated based on Phase I option analysis, that has originated either on or off board. The target type will be used by the SMS to decide on the type and number of weapons to be assigned to that particular target. The source for the on board GPS information will be the simulator in the NAWCADPAX Pilot Vehicle Interface Center (PVIC) and for the off board GPS information will be an emulated system. The off board emulated data could be representative of a pre-flight target set or an in flight third party transmission of target tasking or re-tasking. For pilot designated targets, the same information is transferred to the SMS. In this case, the determination of target type may come from a pattern

classification/recognition algorithm or alternatively the pilot may designate target type. The SMS will make available to the information network the number and types of stores on the aircraft so that real time tasking can be accomplished via the information network. However, when the pilot is designating targets, the SMS will only allow the display of targets that the pilot has the appropriate type and numbers of stores to kill and those targets that are not already assigned to another shooter.

A targeting and stores management display format will be designed for this effort. The actual display of information could be on a heads-down display or, alternatively, a head mounted display. In an all weather, day/night scenario, which is desirable, the use of the head mounted display for this information may help mitigate the loss of spatial awareness that arises in the transition of the pilots visual attention from outside to inside and then outside again. A head mounted display asset would be borrowed from existing assets at NAWCADPAX through the PVIC for this demonstration.

Since 2025-era weapons are not yet defined, the electrical interface requirements for the small smart bomb and the Low Cost Autonomous Attack System (LOCAAS) will be used for the sake of emulation and interface. The total number of weapons to be controlled by the SMS is 256 per station. As previously mentioned, this number has good support from armament system working groups and is supportable within MIL-STD-1760, which is being retained by the JSF program.

In order to demonstrate the automated SMS and its role in the network centric environment, some subsystems must be emulated to augment the PVIC. It is anticipated that several rack-mounted computer systems will be acquired to host software to emulate the various systems. The possible emulated systems are the two weapon types, off board GPS target information, a data fusion process, and possibly a JSF avionics bus characteristic. The full capability of the automated SMS can be explored and demonstrated by varying the capability of the various emulated systems. The conceptual system design is covered in the following sections.

3.3.1 System Components as Related to Mission Type

The various system components illustrated in Figure 3 will play very different roles depending on weapon delivery modes. In close, target of opportunity, air-to-ground attack missions, there will be a tight coupling between the integrated Electro Optic sensing suite, the helmet mounted display and the Stores Management System. In this mode, pre-planned mission goals, long range reconnaissance and other team players have little role. The see-shoot-kill delivery scenarios will not be very different from those already demonstrated in various laboratories. There will be few system design challenges in this attack mode since target designation would involve the digital transfer of a small kernel of data to the active weapon. By 2025, the difficulties in integrating HMDs due to system lags and core processing priority conflicts will be resolved through the introduction of new processing technology and high-speed avionics architectures. The challenge address in this report is that of the stand off air-to-ground attack scenario outlined earlier.

At 80 to 120 miles from the target, onboard EO sensing and RF sensing will not be effective. Pre-planned data loading into the mission data cartridges will be the primary source of targeting information with updates provided by ground, space, and air, manned and unmanned vehicles. The avionics suite aboard ownship will primarily be used for information transfer rather than information gathering. The traditional function of a Stores Management System (to provide the primary electrical / functional interface between the crew, suspension and release equipment, stores, and other aircraft systems for the purpose of controlling and monitoring stores) will need to be expanded for this new mission.

The primary distinction between existing systems and what is being proposed here is that a single player can no longer be treated in isolation. That is, aircrew today know what weapons are loaded on their aircraft and what targets they are to attack. While global mission goals may not be accomplished, a lone aircraft can perform the given mission in isolation. The avionics systems of today are designed so that each aircraft is self-sufficient, but this design hampers cooperative solutions to mission goals.

The standoff air-to-ground attack mission of 2025 will foster cooperative weapon utilization. A weapon load-out of a single aircraft will not be as important as the weapon load-out of the entire strike package. The function of the SMS must include knowledge of the entire strike package load-out and mission goals. Target assignment will be a dynamic process based on off-board target updates, aircraft position and on-the-fly changes on mission goals. The SMS systems of the strike package will participate in an arbitration scheme to optimize weapon delivery. To the aircrew, what this means is that targets will appear on their attack display only if they have been assigned through the cooperative coordination of the entire strike package. These targets may or may not correspond to those discussed in the pre-flight briefing, but they will be appropriate to the weapons on board.

The crew centered armament system concept greatly reduces the workload of the aircrew by only presenting targets that appropriate to mission goals, and that can be handled by the weapons remaining on the store stations. It does no good to present aircrew with an attack display shown below in Figure 6, target rich with no weapons on board.

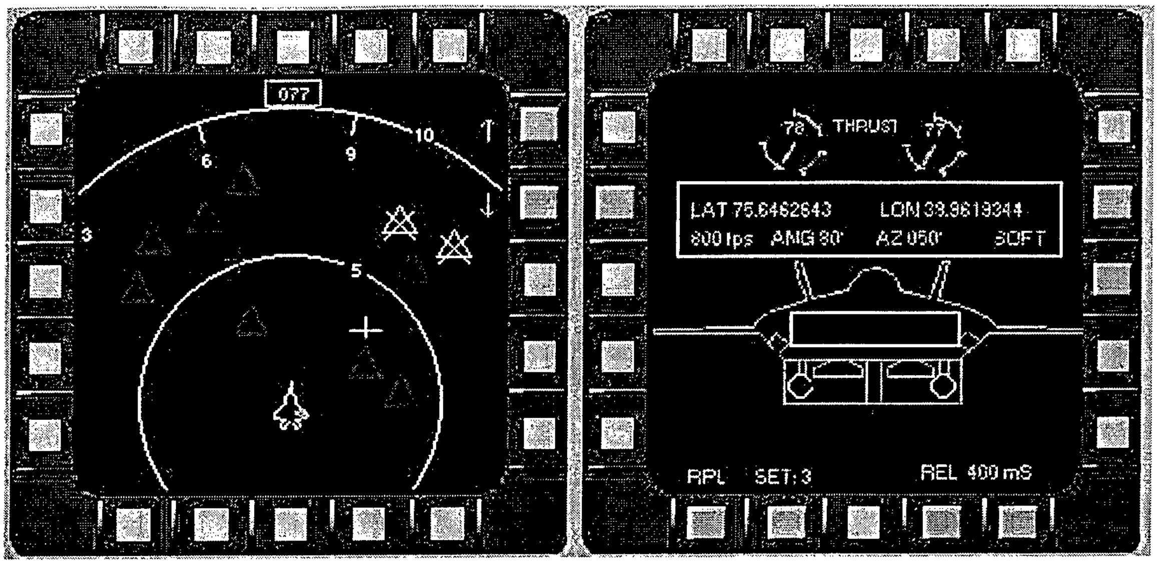

Figure 6, A Non-Crew Centered Armament System Attack Display (1)

The design goal of target identification and designation with 2 seconds precludes aircrew of the attack aircraft be responsible for analyzing satellite imagery in order to designate targets as depicted in Figure 7 below.

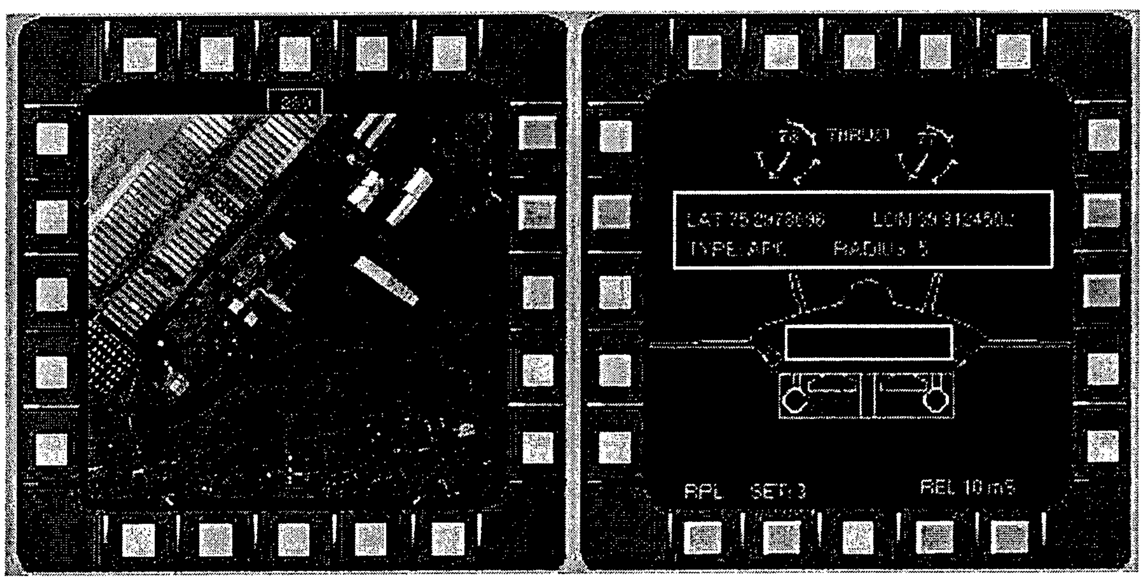

Figure 7, A Non-Crew Centered Armament System Attack Display (2)

The following sections will discuss the conceptual design of the armament system that will support the scenario discussed above.

3.3.2 Traditional SMS Functionality – Updated for Smart Weapons

An excellent report was prepared in 1980 by the Fairchild Space and Electronics Company entitled "Stores Management Systems Architectural Tradeoff Studies". This report goes into great detail on the functional allocation among the various components of a stores management system. While much of this report holds true today, it was generated before the adoption of MIL-STD-1760 and the advent of Smart weapons. In fact, the recommended architecture of this report is in direct conflict with the requirements of MIL-STD-1760 (although the third choice of nine architectures analyzed supports MIL-STD-1760). The first step in the conceptual design process is to update this report for the new class of weapons.

Figure 8, below, illustrates a generalized SMS by functional elements and information paths. These functions must all be accounted for whether the SMS is a single box or a distributed network of computers. For now and for the near future, the interface to the stores will be MIL-STD-1760. Although there have been attempts to modernize this interface based on commercial communications protocols, the established reliability, safety and installed consumer base of MIL-STD-1553 means that this protocol is here to stay for quite some time.

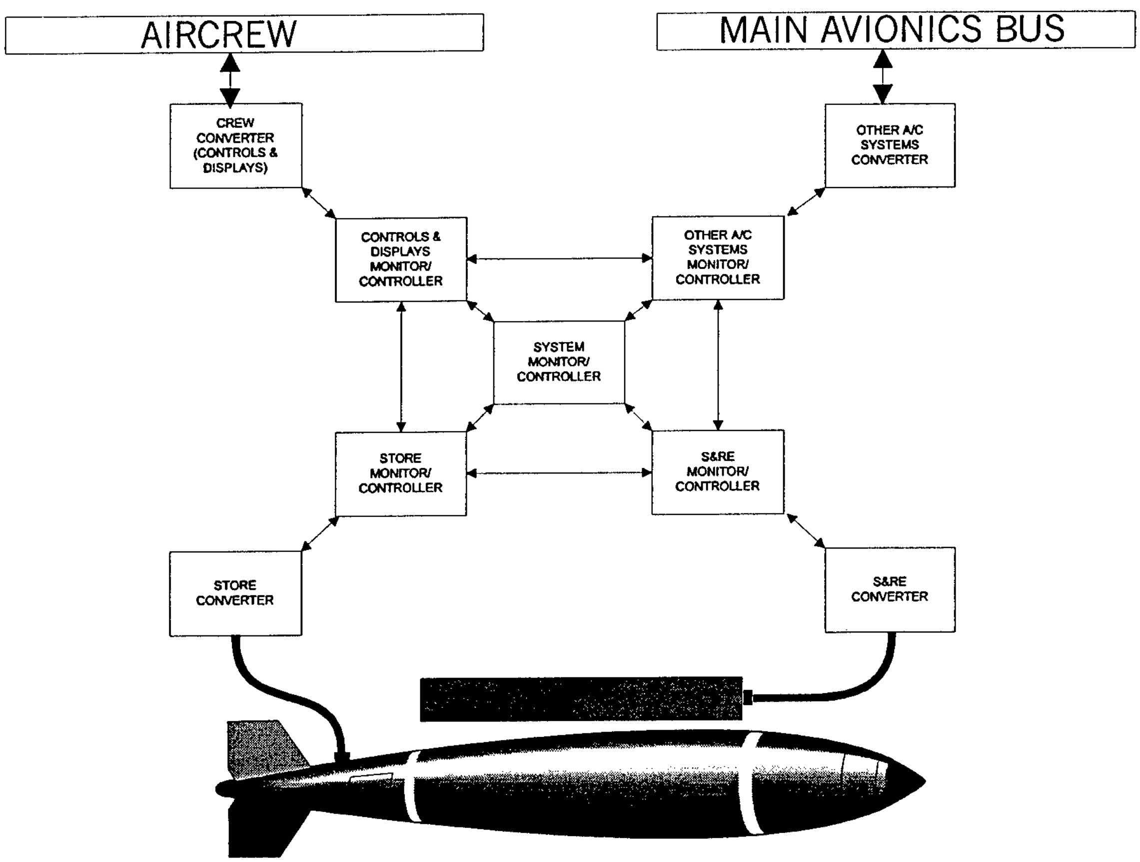

Figure 8, A Generalized SMS by Functional Elements and Information Paths

3.3.2.1 Program – Enter Deliver Program

The following functional requirements were identified in the 1980SMS Architecture report for the mission segment that initializes the SMS and store inventory:

- Enter Delivery Program Name
- Enter Station Number
- Enter Store Type
- Enter Delivery Program Options:
    - Delivery Mode
    - Release Mode
    - Quantity
    - Ripple Interval
    - Maverick TV Contract
    - Fuzing
    - Auto Clear/Non-Auto Clear
    - T_A/T_B
    - Air/Ground
    - Free fall/Retard
    - Fast/Normal Deploy
    - Nuclear Function
- Display Station Number
- Display Store Type
- Display Delivery Program Options: (As above for Entry)

There are several things to note based of the adoption of MIL-STD-1760 and Smart GPS guided weapons. MIL-STD-1760 defines a method that automates store inventory. Through the digital data link, the aircraft is able to determine which store is hanging on a particular station and is also able to tell the store which aircraft and store station it is hanging on. This gives both aircraft and stores Operational Flight Programs (OFP) the ability to automatically adapt deployment methods based on specific configurations. Considerations here include weight and center of gravity balancing, store to store collisions, low observability measures etc.

Many of the functions listed above were communicated by means of analog voltages, pulses where the width conveys in information, wired discrete signals and even mechanical lanyards. All of this information can now be coded into digital messages sent to the stores.

In addition, the initialization of GPS/INS guided smart weapons has become fairly complex. After application of power, the store performs a Built In Test (BIT) and reports its condition. There is then a mass data transfer over the digital link to download many of the parameters in the list above along with, multiple target sets, GPS almanac and ephemeris data, GPS cryptographic keys, way points, end game strategy, etc. These

weapons also require a warm-up period to stabilize their internal Inertial Navigation Subsystems (INS).

3.3.2.2 Program – Modify Inactive Delivery Program

The following functional requirements were identified in the 1980SMS Architecture report for the mission segment that allows for re-initialization the SMS and store inventory:

- Enter/Modify Delivery Program Name
- Enter/Modify Station Number
- Enter/Modify Store Type
- Enter/Modify Delivery Program Options: (As above)

The same design considerations required for 3.3.2.1 hold here also.

3.3.2.3 Program – Enter Selective Jettison Program

The ability to selectively jettison stores is crucial to aircrew safety. Selective jettison will remain a low level function. That is, Emergency and Selective Jettison circuits will most likely remain hardwired to switches in the cockpit rather that being executed over multiple computer links. Although station selection may be through switches on Multi Function Displays, the number of computer systems between the controls and display processor and the Suspension and Release Equipment should be minimized.

- Enter Station Number
- Enter Store Type
- Enter Suspension Type
- Display Station Number
- Display Store Type
- Display Suspension Type
-

3.3.2.4 Program – Modify Selective Jettison Program

- Modify Station Number
- Modify Store Type
- Modify Suspension Type
- Display Station Number
- Display Store Type
- Display Suspension Type

The same design considerations required for 3.3.2.3 hold here also.

3.3.2.5 Attack – Select a Delivery Program

The following functional requirements were identified in the 1980SMS Architecture report for the mission segment that carries out the attack:

- Display Station Number
- Display Store Type
- Display Suspension Type
- Display Quantity Remaining
- Display Preset Options
- Display Store Status
  - Safe, Ready, Tracking, Releasing, Armed, Hung
- Display Delivery Program Options
- Eliminate Completed Delivery Program

The complexity of the initialization of smart weapons prepares them for the simplicity of target designation and release. A single digital message (lasting < 1ms) conveys all the information needed to set an active target.

3.3.2.6 Attack – Modify Active Delivery Program

- Modify Delivery Program Options
- Display Delivery Program Options

Again, with MIL-STD-1760 stores, these functions are easily accomplished through a few MIL-STD-1553 messages. The possible bottlenecks here involve large numbers of weapons scheduled for release at the same time. As stated before, however, MIL-STD-1760 will be the weapon interface for the future so the MIL-STD-1553 design limitations of 1MBps will remain. For the new class of miniature munitions, a new Military Standard is being developed that will define a new communications protocol for use inside dispensers designed to carry the smaller stores in order to address the limitations of using the '1553 communications protocol. The requirement for 256 addressable weapons from a single aircraft store station comes from this new working group.

3.3.2.7 Attack – Prepare Stores Prior to Release

The following functional requirements were identified in the 1980 SMS Architecture report in order to assure that stores are ready to perform their intended mission:

- Prepare Suspension Power
  - Enable/Disable Power to Racks
  - Enable/Disable Power to Launchers
- Select Store
  - Select Store
  - Reject Current Store
  - Activate/Deactivate Rocket/Dispenser Select
  - Select/Deselect Rockets

- Activate/Deactivate Station Select

- Prepare Arming & Fuzing
  - Activate/Deactivate Arm Enable
  - Activate/Deactivate Fuzing
  - Activate/Deactivate Master Arming for External Gun Pod
- Prepare Conventional Stores
  - Activate/Deactivate Auto-Clearing for External Gun Pod
  - Activate/Deactivate Power and Pre-arming for External Gun Pod
  - Activate/Deactivate Fire Enable
  - Activate/Deactivate Battery Heaters
  - Activate/Deactivate Gyroscopes
  - Connect/Disconnect Audio Circuit
  - Connect/Disconnect Video Circuit
  - Activate/Deactivate Attitude Direction Indicator
  - Activate Power Changeover
  - Reset Back to Aircraft Power
  - Activate/Deactivate Squib Arm
  - Cage/Uncage Seeker Heads Electrically
  - Cage/Uncage Seeker Heads Mechanically
  - Activate/Deactivate Missile Guidance Power
  - Activate/Deactivate Environmental Power
  - Activate/Deactivate Slew Controller
  - Enable/Disable Seeker Head Slewing
  - Activate/Deactivate Ordinance Relay
  - Activate/Deactivate Intent to Launch
- Acquire Data for Store Guidance System Alignment
- Acquire data for boresight convergence
- Provide data for alignment
- Provide data for boresight convergence
- Select Store Mode
- Provide Indication of Store Alignment on Target
- Configure Control/Display Mode for Control of Store
- Issue Cues/Advisory Messages
- Acquire Position, Velocity for Release Computations
- Acquire Threat/Target Data
- Provide Target Parameter Data to Store
- Remove Covers from Store

In addition to digital messages that perform the functions listed above, stores that comply with MIL-STD-1760 have a well-defined timeline that ensures the readiness of the store prior to release. The sequence of digital messages commands to store to do a final BIT check, confirm inertial alignment with the aircraft, start up internal batteries, and signal a readiness for release.

3.3.2.8 Attack – Initiate Release

The following functional requirements were identified in the 1980 SMS Architecture report in order to successfully release a weapon:

- Compute Safe Store Release Envelope
- Compute Release Sequence Timing
- Build Release Sequence Table
- Display Release Point Information
- Issue Release Enable
- Issue Release Command
- Eject Store/Activate Prime Mover Devices
- Initiate Firing/Arming Sequence
- Perform Post-Separation Actions
- Update Stores List to Reflect Release of Stores

Some functionality here may be migrated from the SMS into the store itself. Algorithms for calculating a Launch Acceptability Region (LAR) vary from platform to platform. Given that the weapon has knowledge of the platform that is carrying it along with knowledge of the flight conditions (altitude, mach, attitude, etc.) the weapon itself can calculate the LAR and report it to the airframe for display. There is currently an effort underway to standardize the LAR parameters among stores and airframes.

3.3.2.9 Jettison – Select Selective Jettison Program

- Display Station Number
- Display Store Type
- Display Suspension Type
- Establish Conditions for Jettison
- Select Jettison Mode
- Display Jettison Mode, Status
- Eliminate Completed Selective Jettison Program
- Determine Landing Prohibited Stores

There is no impact on requirements for MIL-STD-1760 or Smart Weapons here.

3.3.2.10 Jettison – Selective Jettison

- Safe the Stores to be Jettisoned
- Jettison the Stores
- Update Stores List to Reflect Jettison of Stores

Updates to this list for MIL-STD-1760 and Smart Weapons include the consideration for zeroization of sensitive data stored in the weapons memory. This process should be completed before power is removed from the weapon and the store jettisoned. This process should not be a requirement for jettison as safety overrides security issues.

3.3.2.11 Jettison – Emergency Jettison

- Safe the Stores to be Jettisoned
- Jettison the Stores
- Update Stores List to Reflect Jettison of Stores

Updates to this list for MIL-STD-1760 and Smart Weapons include the consideration for zeroization of sensitive data stored in the weapons memory. This process should be completed before power is removed from the weapon and the store jettisoned. This process should not be a requirement for jettison as safety overrides security issues.

3.3.2.12 Test – SMS

The following functional requirements were identified in the 1980 SMS Architecture report for both in-flight and ground testing:

- Perform Foreground/Background BIT of SMS
- Display Backup Mode Selected for Damaged Aircraft Armament System (AAS)
- Display Optional Damaged AAS Backup Modes
- Allow Selection of Optional Mode
- Record AAS Status at Each Change and Completion of BIT
- Verify In-flight Lock System Activated
- Verify AAS Safed for Landing
- Verify Landing Prohibited Stores are Jettisoned
- Verify Master Arm is Deactivated

There are no updates to these requirements based on MIL-STD-1760 stores.

3.3.2.13 Test – Stores

The following functional requirements were identified in the 1980 SMS Architecture report for both in-flight and ground testing:

- Display Backup or Degraded Mode Selected for a Store that Fails BIT
- Query Crew for Optional Backup or Degraded Modes
- Verify Proper Environmental Conditions are Met Prior to Release of Store
- Verify Covers Removed from Store
- Verify Power Available to Store
- Verify Store Tracking Locked on Target
- Verify Data Link Established to Store
- Verify Stores are Safed for Landing
- Verify Trackers/Seekers are Disabled for Jettison

There are no updates to these requirements based on MIL-STD-1760 stores.

3.3.2.14 Test – Suspension and Release Equipment

The following functional requirements were identified in the 1980 SMS Architecture report for both in-flight and ground testing:

- Verify Proper Release of Store
- Verify Ability to Jettison
- Verify Proper Jettison of Stores

With the introduction of stores that carry other stores such as the BRU-57 Smart Rack and SWARMER which is the carriage system for the new generation of miniature munitions, testing of S&RE has moved one level down on the hierarchy. These carriage systems now have the responsibility of the S&RE originally relegated to the parent pylon. Status of the carriage S&RE is determined through digital messages over the MIL-STD-1553 bus. The carriage systems are themselves MIL-STD-1760 stores and as such inherit all of the properties and requirements discussed previously.

3.3.2.15 Aircraft Systems Interface

The following functional requirements were identified in the 1980 SMS Architecture report to handle the flow of information from the aircraft primary avionics system down to the stores management system:

- Support Flight Control System (FCS) with Current Stores Configuration on an Update/Continuous Basis
- Acquire Position, Velocity for Flight Vector Computations
- Compute Flight Vectors
- Provide Flight Vectors to Target to FCS
- Inform FCS of Reaction Forces and Flight Characteristics Changes Due to Release of Store
- Minimize Store Induced Drag Effects
- Control Dynamic Stress
- Computer Post-Separation Profile
- Display Post-Separation Profile
- Provide Post-Separation Flight Vectors to FCS

In addition to the discrete mission events of initialization and release, GPS/INS weapons require constant updated en route. In order for these weapons to achieve published accuracy, there needs to be a precise alignment of the inertial platforms between aircraft and weapon. This alignment takes place in the form of a periodic exchange of messages between aircraft and weapon while the weapon is energized.

3.3.3 Cooperative SMS Functionality – The "Super" SMS

The following design assumptions were discussed in earlier sections:

- Very rapid targeting required.
- Long standoff range for weapons release.
- Small Smart Bombs. (GPS/INS guided)
- Standoff Hunter-Killer type weapons. (LOCAAS type)
- Target type designation to assist in number and type of weapons available.
- Total number of weapons capable of communication = 256 per pylon.
- No on-board target recognition of image data.
- Three operating modes:
  Downloaded target set (GPS coordinates and target type)
  Pilot target designation from target grid
  Target of Opportunity
- HMD role as Air-to-Surface Display not Primary Target Designator.

The conceptual design for the Crew Centered Armament System has the following goals:

- Expand the concept of an SMS from a single ship to the entire strike package
- Minimize Aircrew Workload
  - Hide many of the routine SMS functions
  - Simplify Attack displays
  - Minimize the need for any SMS cockpit displays
  - Eliminate aircrew target/weapon compatibility decisions
- Introduce automated robustness in the strike mission

3.3.3.1 The Super SMS Does Not Reside Within a Single Airframe

Even with existing and conceptual avionics architectures, the entity "Stores Management System" is seen as a black box or set of black boxes housed within a single airframe. The network centric paradigm paves the way for the definition of and SMS that is distributed among the players of a strike package.

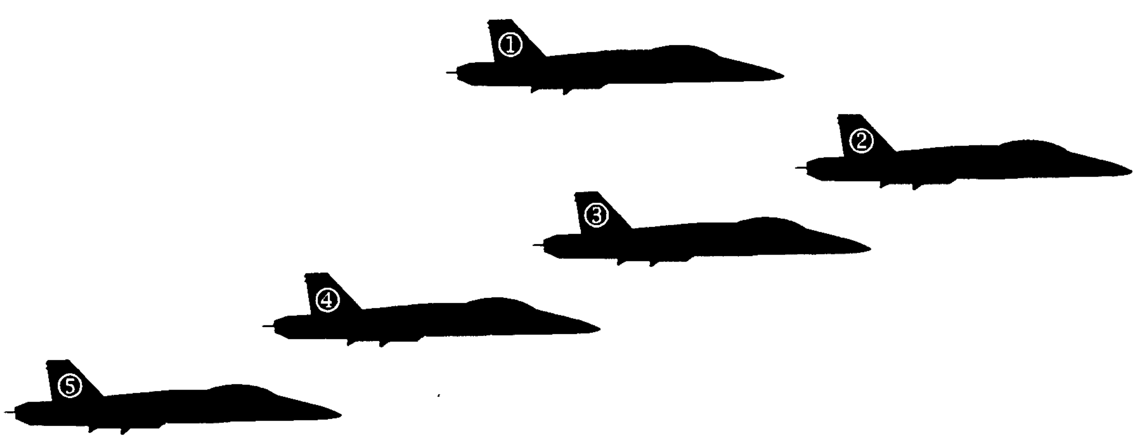

Figure 9, A Five Element SMS

Instead of the SMS handling the inventory and target set of a single ship, the black boxes will be responsible for reporting inventory and status of carried stores and receiving target information for incorporation into the attack display.

Initialization of inventory would take place among many players. Using the five ship example shown above in Figure 9:

- Aircraft 1 would:
  - Initialize stores
  - Build the active inventory (Stores that fail BIT would not be included)
  - Build target list from pre-flight mission planning
  - Pass inventory and target list to aircraft 2

- Aircraft 2 would:
  - Perform all tasks associated with A/C 1 plus
    - Acknowledge receipt of inventory and target list from A/C 1
    - Add ownship inventory and targets to list
    - Pass the list to Aircraft 3

- Aircraft 3-5 (same as Aircraft 2)

- Aircraft 5 would then:
  - Begin target assignment by matching targets with inventory
  - Select a subset of targets for ownship
  - Pass the list to aircraft 4 for target selection, etc.

When the initialization transaction is complete, each ship will have a set of targets appropriate for its active weapon load. While this may seem similar to pre-planning target assignment, consider the following scenario.

The pre-flight planning assigns each target an associated priority for the strike mission. Assume that ship #1 was assigned high priority targets. While initializing the weapons on ship #1 it is discovered that two of the six weapons report that BIT failed. Without this proposed automated SMS, the targets associated with the failed weapons would have to be manually transferred to another ship thus increasing the workload for al least two of the aircrew along with mission planners. With a co-operative multi-ship SMS, the re-shuffling of targets to capable weapons on other platforms is transparent to the aircrew. Pilots will still see targets on their attack display that they are capable of striking.

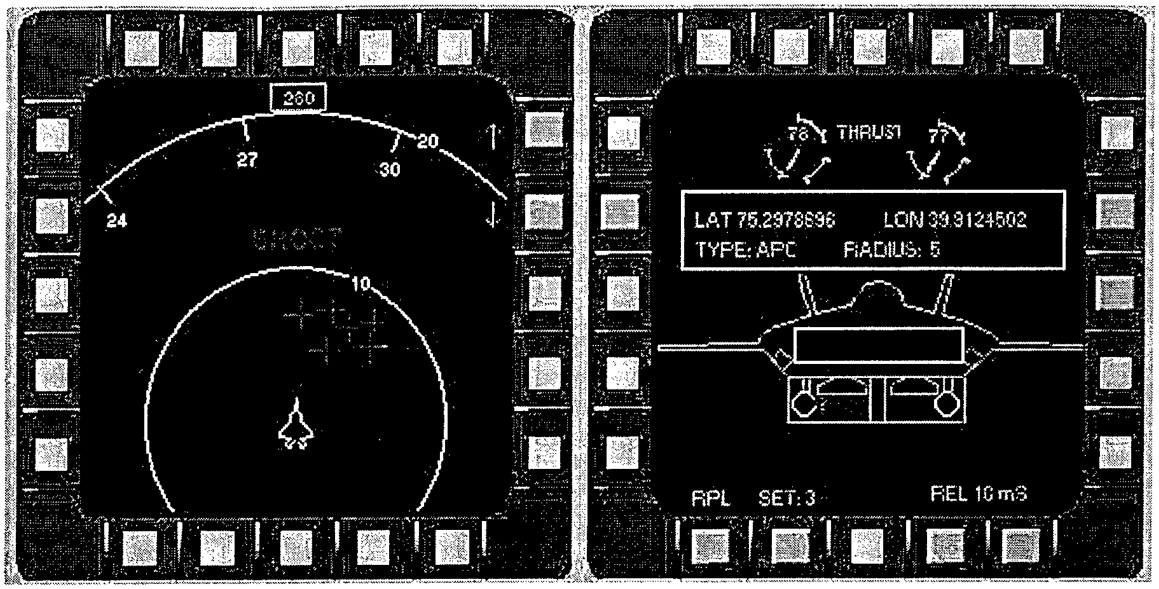

Figure 10, A Crew Centered Armament System Attack Display (1)

The targets on the attack display in Figure 10 may or may not be those assigned to that particular ship.

Since each aircraft has knowledge of the entire strike mission and can cycle target assignment in the span a few milliseconds, a similar transparent reshuffling can also occur when:

- One or more aircraft in the strike package are incapable of completing the mission
- New targets are uploaded en route via C^4ISR platforms
- Weapon failures are detected anytime up to deployment
- Flight is diverted from pre-planned route

This concept can easily be extended to UCAV operations where instead of other strike aircraft, the other elements of the multi-ship SMS are UCAVs with their own associated inventory and target assignment. The advantage of the Crew Centered Armament System can be highlighted here since manual management of the extended store stations (UCAV hard points) would place an overwhelming burden on aircrew.

The "Super" SMS extends the boundary of what is considered an SMS as illustrated below in Figure 11.

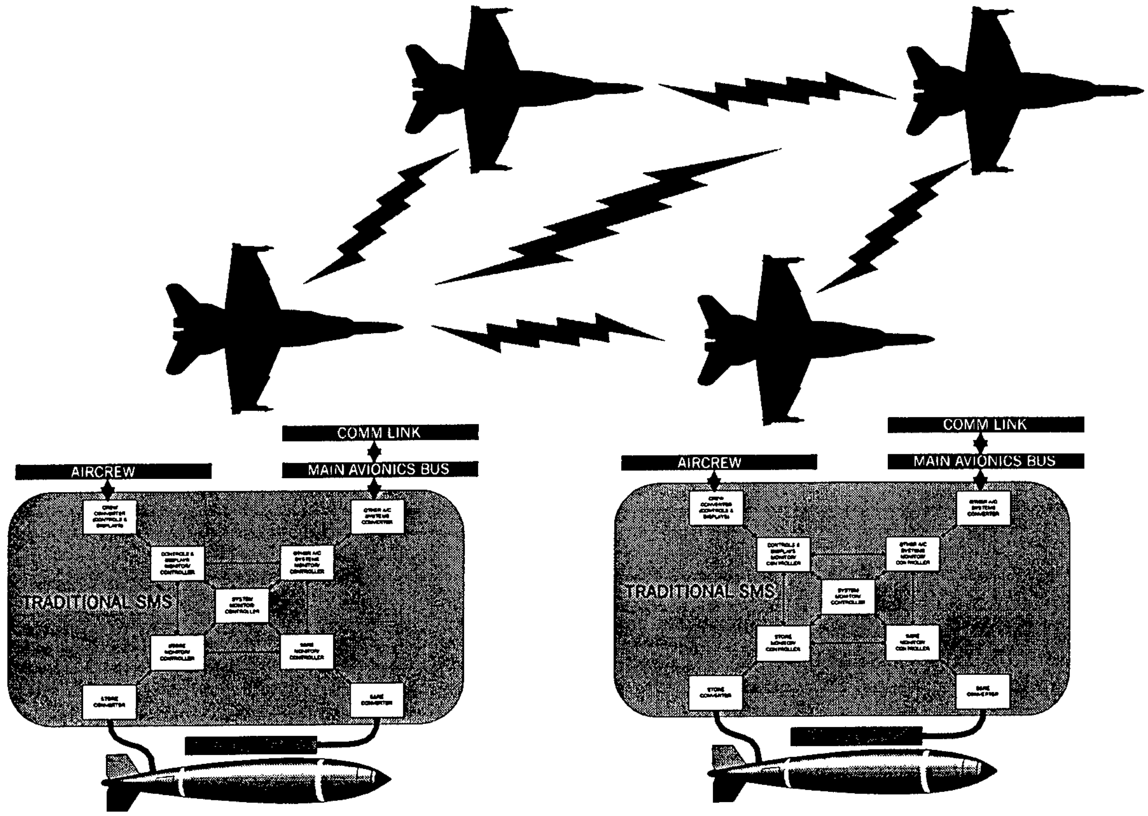

Figure 11, The Extended "Super" SMS

The Key Design Elements of the Crew Centered Armament System are:

- Automated Stores Management System (ASMS)
- Act like a data network management system
- Act like another entity on a network with other aircraft ASMS
- Send weapons status data to aircraft and network.
- Receive target location and type data from aircraft and network.
- Access, control, monitor and track 256 weapons per pylon on-board.
- Display only targets that:
  - the pilot has the weapon to attack
  - are as yet unassigned to another asset
- Use HMD as target display to increase situational awareness.

3.3.4 SMS Strike Mission Functions

Table 6 and Figure 12 below represent a notional chronological flow of Stores Management System (SMS) functions during a typical attack mission based on the strike mission phases and SMS functions described previously. This is not intended as an exhaustive representation of all possible scenarios. However, it provides a basic

understanding of some of the interaction between the ground crew/aircrew and the SMS. As proposed herein, in the future many of these activities could become automated.

Presently, the ground crew personnel are responsible for the following data management activities:

- Enter initial inventory
- Ground test the SMS
- Retrieve mission history

The flight crew is typically responsible for entering and modifying programs. This can be done on the ground or while airborne. In the future, it is conceivable that the ground crew could enter programs.

Table 6, Aircraft & Stores Management System (SMS) Notional Timeline

Time	Aircraft Scenario	SMS Scenario		
		Normal Delivery	Selective Jettison	Emergency Jettison
-01:00 – -00:05	Preflight	Enter Initial Inventory		
		Test SMS		
-00:05 – 00:00	Launch			
00:00 – 00:05	Climb	Enter New Delivery Program	Enter New Selective Jettison Program	
		Modify Inactive Delivery Program	Modify Selective Jettison Program	
00:05 – 00:15	Air refueling			
00:15 – 00:45	Cruise Out	Test SMS, Stores, S&RE	Select A Selective Jettison Program	Emergency Jettison
			Selective Jettison	
00:45 – 00:55	Descent	Select A Delivery Program		
00:55 – 01:05	Ingress	Prepare Stores Prior To Release		
01:05 – 01:15	Attack	Initiate Release		
01:15 – 01:25	Egress	Control Stores After Release		
01:25 – 01:30	Climb			
01:30 – 01:40	Air Refueling			
01:40 – 01:55	RTB			
01:55 – 02:05	Descent			
02:05 – 02:10	Recovery			
02:10 – 02:30	Post Flight	Retrieve Mission History		

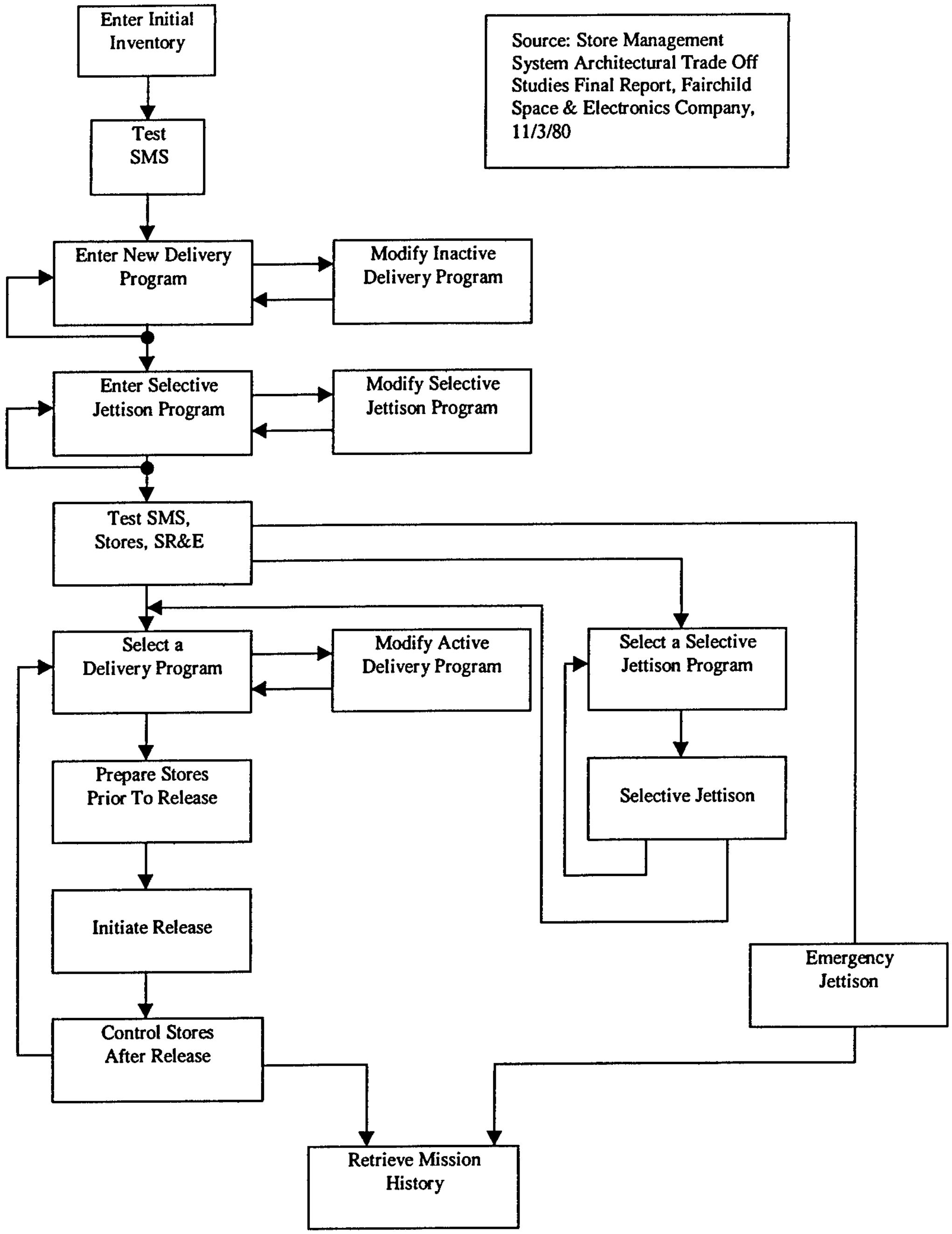

Figure 12, Notional Stores Management System Scenario

4 Discussion

At this present time, the concentration on an automated SMS is warranted for the following reasons. Clearly from the Science and technology plans, more sophisticated air-to-surface weapons are being developed and desired for future strike mission. These weapons will be small and independently capable of target tasking from an outside source

or loiter with target recognition to wait for a target. These weapons will be smaller and lighter, which will allow more weapons to be carried on an aircraft and likely less aircraft needed to prosecute a mission. Given these conditions, the pilot's role is less and less needed to actually interface with the weapon to employ them for a target strike. In addition, the sheer number of weapons onboard, which are rapidly tasked in an asynchronous fashion, makes it impossible for the pilot to manage the stores. An automated SMS is clearly needed to handle the interface with the multiple stores types, interface with the information network, make decisions on the number and type of stores to be employed on a target, keep track of stores composition for the aircraft and to be available for the information network, and provide a filtered display of available targets when necessary.

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6 Appendix A.

Operator										Commander				
Sensor				A/S Shooter						Final Control Authority			Top-Level Requirements	
Use More Than One Information Source	Effective Resolution	Uses More Than One Spectrum	Eagle Eyes - Long Range Vision	Shoots at a Distance	Hits Many Targets In One Pass	Hits Target	Efficient Weapon Use	Manages On-Board Stores	Possess Target Information	ROE	All Weapon Stores Assignment	Weapon Release	Conceptual Design Characteristics	DIRECTION OF IMPROVEMENT
1	1	3	3	1	9	9	1	3	9	3	3	9	IMPORTANCE	
												◉	Weapons Release Discrete Control	
								◉			◉		Stores Type/Allocation Menu Control	
												◉	Weapons Release Advisory Display	
								◉			◉		Stores Allocation/Type Display	
										◉			RTIC to Transmit Command Auth. to ROE	
										◉			Command Information Display	
										◉			Command Information Advisory Tone	
	◉								◉				On-Board Targeting Image Data	
	◉								◉				Off-Board Targeting Image Data	
	◉					◉			◉				On-Board Target GPS Coordinate ID	
	◉					◉			◉				Off-Board Targeting GPS Data	
						○			◉				RTIC On Target Priority	
								◉					Automated Tracking of Stores Utilization	
								◉			◉		User Control to Allocate Store	
							◉	◉					Off-Board Target Type-Weapon Type Data	
							◉	◉					Off-Board Target Type-Weapon Type Numbers Data	
							◉	◉					User Controlled Target Type w/Automatic Weapon Type	
							◉	◉					User Controlled Target Type w/Automatic Weapon Numbers	
						◉							User Target Designation Control	
						◉							User Target Designator Display Reticule	
						◉							RTIC Target Data	
					◉								Multiple Target Designation by User	
				◉									Long Range GPS A/S	
							◉						Self Configurable GPS A/S Weapons	
					◉		◉						Many Small GPS A/S Weapons	
			◉										On-Board Long Range Vision	
◉			◉										RTIC Theater Vision	
		◉											FLIR Sensor	
		◉											I2R Sensor	
		◉											RF Sensor	
		◉											RADAR Sensor	
		◉											UWave Sensor	
◉													RTIC Battlecube	